The influence of screw type and osseointegration ratio on stress distribution in two different endosseous implants

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The purpose of this study is to examine the effect of partial osseointegration situation on bone loading patterns around two different free-standing screw shaped implants (Nobel Biocare, Gothenburg, Sweden and Degussa-Huls, Hanau, German). Two dimensional axisymmetric Finite element models of two implants(10mm length and 4mm diameter) were created according to different bone quantity, quality and osseointegration ratio in maxilla and mandible bone. At the same time uni-cortical and bi-cortical fixation were analyzed.
Generally, full bond case showed less stress than partial bond case in overall area and mandibular model showed less amount of stress than that of maxilla model. Maximum stress of the Branemark implant is higher than that of ANKYLOS regardless of bonding ratio at crestal and apex region. However, more stress concentration was noted in ANKYLOS implant at screw body area especially in mandible. The effect of bicortical fixation on crestal bone stress reduction is dramatical in mandible however, there was no significant effect in maxillary case. The effect of partial bond on stress distribution was more significant at screw body and apex region than in crestal region. Partial bond cases demonstrated greater stress accumulation in trabecular bone than cortical bone.
It is concluded that the more accurate model of implant and bone which affects stress and strain distribution is needed to mimic in vivo behavior of implants.

Since the long-term high success rate of the screw type implants was documented in the literatures, osseointegrated implants has become one of the reliable treatment options in dentistry[1,2]. After osseointegration occurred, maintenance of osseointegration is the key factor for long-term clinical success of the implants. Bone is a living tissue that remodels, i.e. changes its geometry, density, and structure. Bone remodelling is a sequence of biological processes which are mediated by a number of factors, mechanical load, hormonal effects, nutrition and neuronal influences[3]. The effect of mechanical loading to bone was well described by Wolff and Frost[4]. He stated that the change in the function of a bone causes a change in the internal and external conformation of the bone. This process called bone adaptation. Not only the strain level, but also the rate of strain change, the number of strain cycles and the strain distribution change influence the bone response[5,6].

It is very difficult to analyze actual clinical conditions in in vitro experiments. Bone adaptation to altered loading condition around the implants is not only influenced by the mechanical stimuli but also by cascade biological responses[7-9]. However, general information of load distribution can be obtained through nondestructive method, such as finite element method which analyze stress by mathematical calculations. A number of clinical situations were investigated by using finite element analysis so far[10,11]. However, the real clinical situation of implant bone interface in the jaw bone was not considered. Osseointegration to implant material is not occurred perfectly. The contact ratio of bone to implant varies according to types of bone, implant surface conditions and functional stress etc. The purpose of this study is to examine the effect of partial osseointegration situation on bone loading patterns around two different free-standing screw shaped implants (Nobel Biocare, Gothenburg, Sweden and Degussa-Huls, Hanau, German).

MATERIALS AND METHODS

Two dimensional axisymmetric finite element models of a Branemark(Nobel Biocare, Gothenburg, Sweden) and a ANKYLOS (Degussa-Huls, Hanau, German) implant surrounded by different bone quantity and quality according to arch shape were created respectively as shown in Fig. 1 and Fig. 2. The ANSYS 5.5 software was used for modelling and analyses. To compare the same dimension, 10mm length and 4mm diameter of each implant was modelled. Axisymmetric models were used to study the bone loading patterns of bicortical and unicortical anchorage cases of both maxilla and mandible bone (Fig. 1 and 2). The average dimensions of each jaw bone were measured in dissected skull. For bicortical fiaxation case, the implant apex is placed 1mm deep in the apical cortex.

To mimic the clinical situations, the different bonding ratios of bone-implant interface were giv-

Table 1. The properties of each bone and implant.

	Young's modulus	Poisson's ratio
Implant	117 GPa	0.3
Cortical bone	13.7 GPa	0.3
Cancellous bone	1.37 GPa	0.3

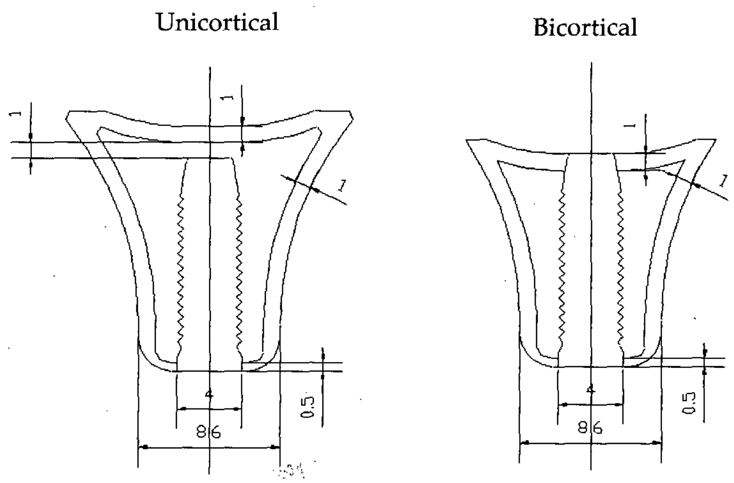


Fig. 1. Dimensions of maxilla model and implant.

en to cortical and cancellous bone each. The bonding ratio was assumed as shown in Fig. 3 and Fig. 4 based on several autopsy studies. A 0.05mm thin layer was modelled around entire implant body and the very small Youngs modulus was assigned to given numbers of elements according to bonding ratio.

The material properties are given in Table 1. The representative figure of the finite element model is shown for reference in Fig. 5. The 480N axial force was applied to each model. The bottom of the mandible model and top of the maxilla model were fixed to prevent any displacement of bone during loading situation (Fig. 5). Finally, Von Mises stress of each case at 0.05mm apart from interface was obtained under the various conditions.

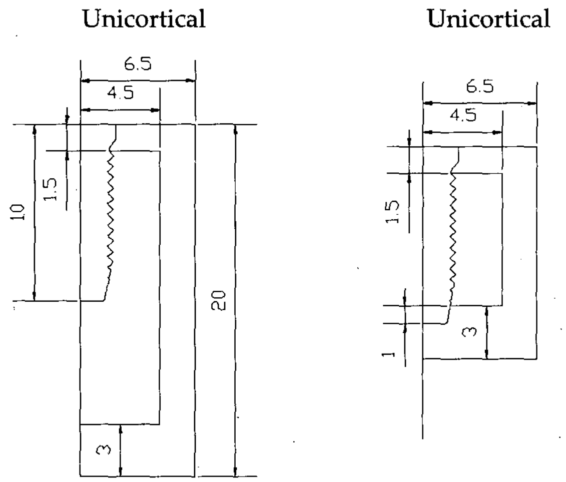


Fig. 2. Dimensions of mandibular model and implant.

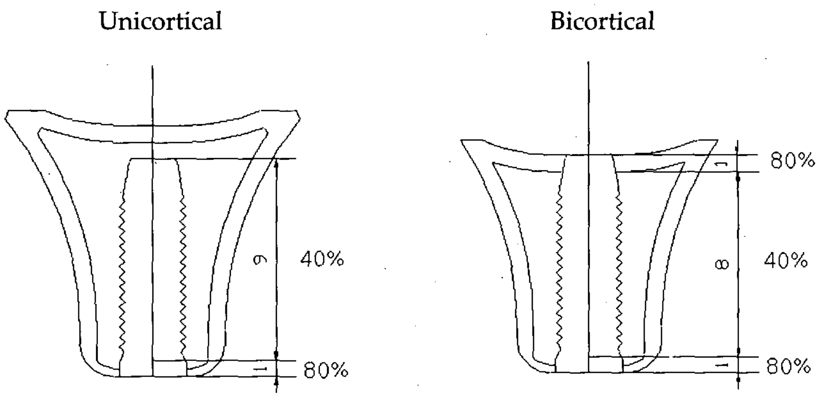


Fig. 3. Given bonding ratio of cortical and trabecular bone in maxilla.

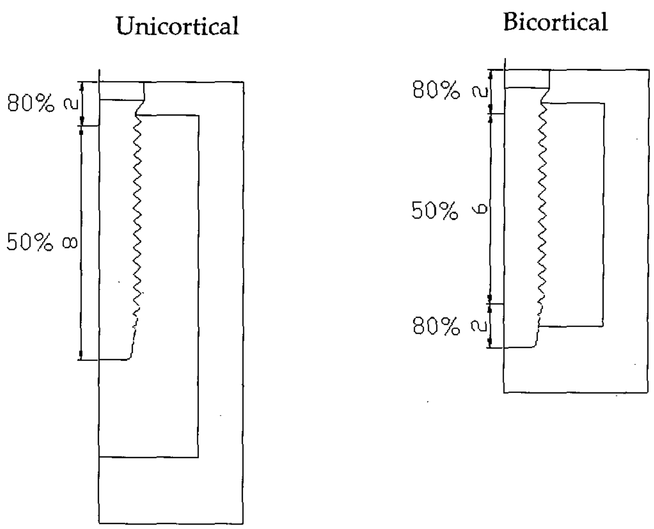


Fig. 4. Bonding ratio of cortical and trabecular bone in mandible.

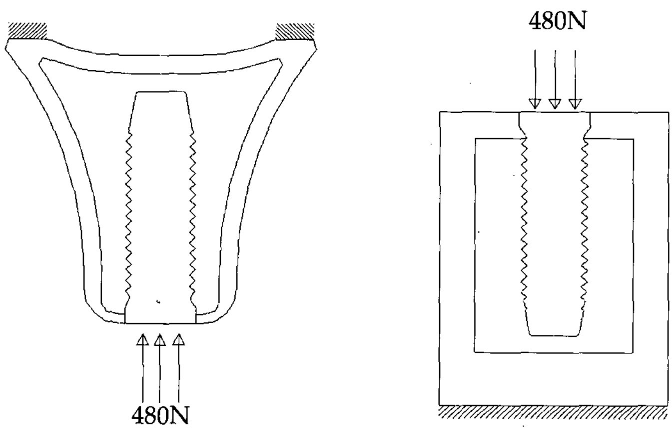


Fig. 5. Fixation area and loading condition.

RESULTS

Table 2~3 shows the Von mises stress distribution in cortical and trabecular bone under axial load of 480 N for a full bond case and a partial bond case respectively. It represents the results of bicortical fixation and unicortical fixation also.

Generally, full bond case showed less stress than partial bond case in overall area and mandibular model showed less amount of stress than that of maxilla model. In comparison of full and partial bonding situation, Branemark and ANKYLOS implant showed 12% to 27% and 8% to 33% more stress concentration respectively at crestal region in partial bond situation. The amount of maximum stress at screw body area increased 127%

Table 2. Maximum Von Mises stress(MPa) in implant.

			Neck area		Screw		Apex	
			Branemark	Ankylos	Branemark	Ankylos	Branemark	Ankylos
Mandible	Uni-cortical	case1	43.9	40.0	7.0	9.5	9.6	9.5
		case2	55.7	53.0	15.9	16.6	21.8	18.7
	Bi-cortical	case1	24.0	21.9	2.7	5.7	29.5	25.8
		case2	31.6	23.7	6.6	6.7	44.4	46.9
Maxilla	Uni-cortical	case1	55.6	49.9	8.5	8.4	8.3	8.8
		case2	63.7	58.1	21.5	18.6	23.2	20.0
	Bi-cortical	case1	60.5	54.6	9.6	8.6	39.5	22.1
		case2	68.4	62.4	22.5	21.2	56.1	28.4

Table 3. Average Von Mises stress(MPa) in implant.

			Neck area		Screw		Apex	
			Branemark	Ankylos	Branemark	Ankylos	Branemark	Ankylos
Mandible	Uni-cortical	case1	20.2	19.0	2.9	3.1	5.5	5.1
		case2	25.1	23.5	5.0	4.8	9.4	11.4
	Bi-cortical	case1	11.6	10.3	1.5	2.8	15.2	21.5
		case2	13.7	12.4	2.0	3.3	18.3	28.9
Maxilla	Uni-cortical	case1	28.4	24.8	3.9	4.1	5.1	4.0
		case2	36.2	32.2	7.4	6.8	9.7	10.1
	Bi-cortical	case1	31.0	27.4	4.2	4.8	12.6	18.2
		case2	38.8	35.1	7.7	7.5	16.9	21.7

to 153% in Branemark implant and 18% to 147% in ANKYLOS implant respectively. At the apex, the difference of maximum stress between Branemark and ANKYLOS was 42% to 180% and 29% to 127%.

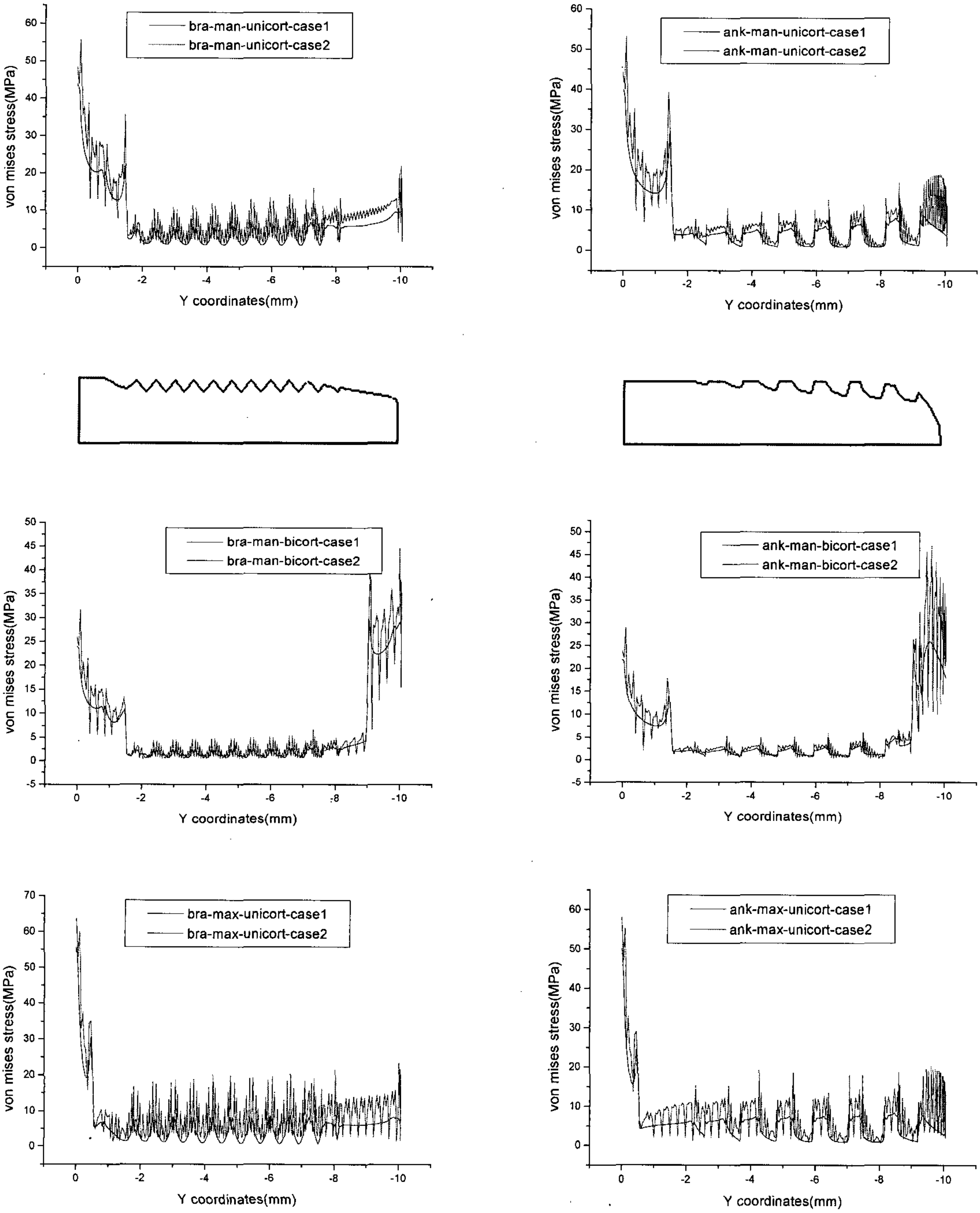
Maximum stress of the Branemark implant is higher than that of ANKYLOS regardless of bonding ratio at crestal and apex region. However, more stress concentration was noted in ANKYLOS implant at screw body area especially in mandible (Table 2).

The effect of bicortical fixation on crestal bone stress reduction is dramatical in mandible however, there was no significant effect in maxillary case (Table 2).

There is almost 50% stress reduction effect at cervical cortex in mandibular bicortical fixation case. However, there is less than 10% stress reduction effect of bicortical fixation in maxilla situation. The effect of bond ratio is more significant in maxilla than mandible regardless of implant shape.

A huge difference in stress values between the cervical cortex and trabecular bone was noticed regardless of bone configuration especially in mandible. In trabecular bone stress and strain peaks occurred at the tips of the screw thread. The pattern of stress is different to screw designs however, the amount of stress is similar to regardless of screw shape in maxillary trabecular bone.

Fig. 6. Comparison of full bond and partial bond case.
Case 1 - full bond
Case 2 - partial bond



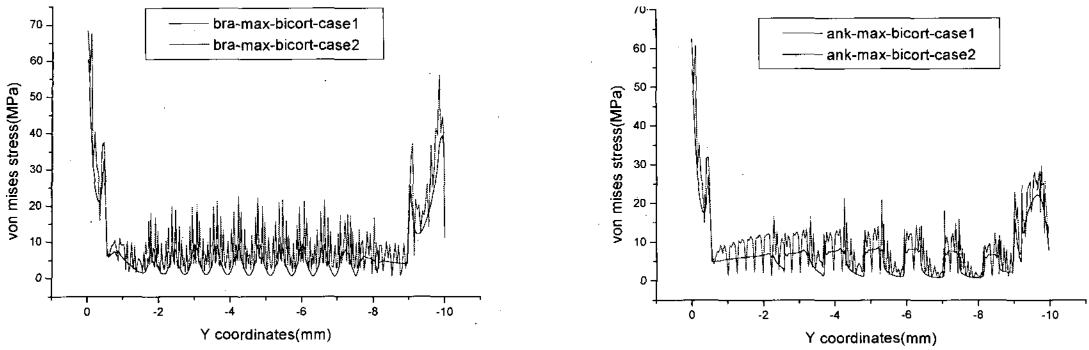
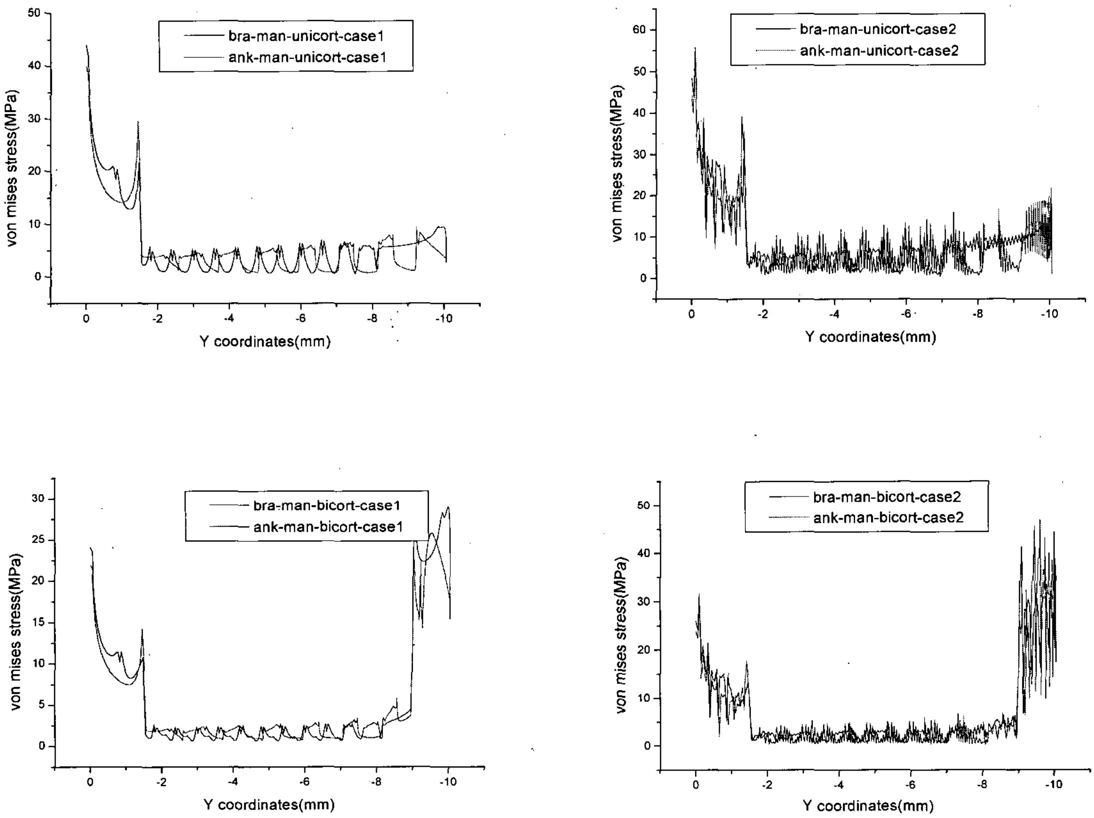
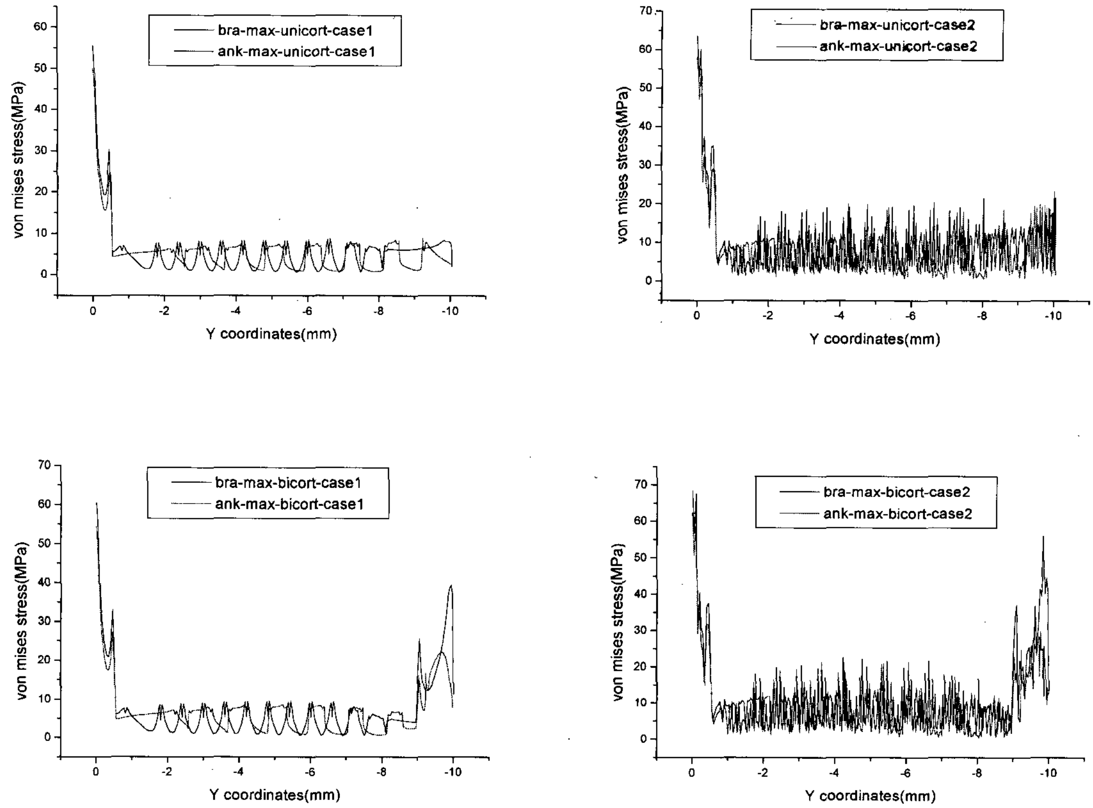


Fig. 7. Comparison of Branemark and Ankylos implant.
Case 1 - full bond
Case 2 - partial bond





DISCUSSION

Some assumptions and simplifications have been made with regard to the material properties and model geometry. Bone tissue is assumed to have uniform isotropic elastic properties, although bone will exhibit a more complex situation in vivo. Implant bone interface conditions, as indicated, have a very strong influence on the bone loading patterns around the implant. The level and mode of stress and strain distribution are highly affected by the interface conditions[10]. Even though the amount of stress is not a actual number, the general tendency of stress distribution can be analyzed in this model.

To mimic real clinical situation of osseointegration ratio, the average osseointegration ratio based on several autopsy study was applied to cortical and cancellous bone model in this study[12-16]. It is also meaningful to analyse stress at various locations of a implant body such as crestal, screw body and apex region.

The full bond case showed less stress accumulation on overall implant surfaces.

The effects of partial bonding is greater in screw body and apex area than in crestal region. The amount of stress is greater in crest and apex than screw body area. It seems that bone quality and bone amount exaggerated the stress accumulation in each jaw model. Especially in mandible model where the lower cortical layer is thicker than upper cortical layer more stress was concentrated at apex area than crest. Consequently the effect of bicortical fixation was great in mandible. There are two mechanical explanations of crestal bone resorption phenomenon. One is overloading of the implant and the other is a stress shielding effect[17-19]. In unicortical fixation case, stress accumulation seems to be a plausible explanation however, stress shielding effect resulting from too rigid anchorage seems to be a possible explanation in bicortical fixation case[17]. At the moment, there are many suggested reasons for crestal bone resoption such as surgical trauma, biological width and stress. So far, no conclusive explanation of marginal bone loss was reported. As reported in previous studies, this study supported that the amount of stress and strain can be significantly affected by bone quality, configuration and bonding ratio also.

Generally, stress accumulated at crest and apex area. There was no significant advantage of bicortical fixation at crestal and screw body region in maxilla as reported earlier[11]. It may be postulated that thin layer of cortical bone, soft bone quality and surrounding bone configuration of maxilla contributed the results. Recent long-term clinical observation study also indicated that no evidence of advantage of bicortical fixation of 10 mm implants on implant success[17]. The marginal bone loss was alomost identical regardless of fixation method for 15 years[17].

However, bicortical fixation reduced stress at crestal and screw body region dramatically in mandible(43% to 60%). It also showed even stress distribution. Shape and lower cortical bone thickness of mandible may contribute to stress reduction at crestal and screw body. On the contrary to maxilla, the shape and thickness of cortical bone of mandible is quite different, especially the thickness of cortical bone may affect the stress distribution mainly.

The average stress at screw body area demonstrated no significant difference between two implants (less than 10%). Although the average amount of stress is different according to screw design, it has not as much effect as bone quality and thickness on stress distribution.

CONCLUSIONS

Following conclusions were drawn within the limits of this study.

1. Full bond case showed less stress than partial bond case in overall area.
2. The effect of partial bond on stress distribution was more significant at screw body and apex region than in crestal region.
3. Partial bond cases demonstrated greater stress accumulation in trabecular bone than cortical bone.
4. Branemark implant demonstrated more stress accumulation than ANKYLOS implant at crestal and apex area. However, ANKYLOS implant showed more stress at screw body area in full bond mandible case only.
5. The stress distribution effect of bicortical fixation was great in mandible however, there was no siginificant effect in maxilla.

Acknowledgment

The author would like to express appreciation for the assistance of professor Joo-Ho Choi, Department of Aeronaufical & Mechanical Engineering, Hankook Aviation University.

REFERENCES

1. Adell R, Eriksson B, Lekholm M, Branemark P-I and Jemt T. A long term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. Int J Oral Maxillofac Implants 1990;5:347-359.
2. Lekhom U, Gunne J, Henry P, Higuchi K, Linden U, Bergstrom C, van Steenberghe. Survival of the Branemark implant in partially edentulous jaws: A 10-year prospective multicenter study. Int J Oral Maxillofac Implant 1999;14:639-645.
3. Betram J, Swartz S. "Law of Bone Transformation": a case of crying Wolff? Biological Review 1991;66:245-273.
4. Frost, HM. A determinant of bone architecture: the minimum effective strain. Clinical Orthopaedics 1983;175:286-292.
5. Lanyon LE, Goodship AE, Pye CJ, MacFie JH. Mechanically adaptive bone remodelling. J of Biomechanics 1982;15:141-154.
6. Rubin CT, Lanyon LE. Regulation of bone formation by applied dynamic loads. J of Bone and Joint Surgery 1984;66-A:397-402.

7. Shenk R, Hunziker EB. Histologic and ultrastructural features of fracture healing. In Brighton CT, Friedlander G, Lane JM(eds). Bone Formation and Repair. Rosemount, IL:American Academy of Orthopaedic Surgeons, 1994:117-146.
8. Roberts WE. Bone tissue interface. J Dent Educ 1988;52:804-809.
9. Isidor F. Histological evaluation of peri-implant bone at implant subjected to occlusal overload or plaque accumulation. Clin Oral Impl Res 1997;8:1-9.
10. Van Oosterwyck et al. The influence of bone mechanical properties and implant fixation upon bone loading around oral implants. Cli Oral Impl Res 1998;9:407-418.
11. Choi JH, Seo KY, Choi JH and Han JS. Effects of bone engagement type and implant length on stress distribution: A three dimensional finite element analysis. J Korean Acad Prosthodont 1999;37(5);687-697.
12. Rohrer MD, Sobczak RR, Prasad HS and Morris HF. Postmortem histological evaluation of mandibular titanium and maxillary hydroxyapatite coated implant from 1 patient. Int J Oral Maxillofac Implants 1999;14:579-586.
13. Dominici JT, Olsen JW, Rohrer MD, Morris HF. Postmortem histological evaluation of hydroxyapatite coated cylinder and titanium alloy basket implants in situ for 37 months in the posterior mandible. Implant Dent 1997;6:215-222.
14. Rohrer MD, Bulard RA, Patterson MK. Maxillary and mandibular titanium implants 1 year after surgery: Histologic examination in a cadever. Int J Oral Maxillofac Implants 1995;10:466-473.
15. Nystrom E, Kahnberg K, Albrektsson T. Treatment of the severely resorbed maxilla with bone graft and titanium implants. Histologic review of autopsy specimens. Int J Oral Maxillofac Implants 1993;8:162-172.
16. Wilson TG Jr, Schenk R, Buser D, Cochran D. Implants placed in immediate extraction sites: A report of histologic and histometric analyses of human biopsies. Int J Oral Maxillofac Implants 1998;13:333-341.
17. Ivanoff CJ, Grondahl K, Bergstrom C, Lekholm U and Branemark PI. Influence of bicortical or monocortical anchorage on maxillary implant stability: A 15-year retrospective study of Branema가 system implants. Int J Oral Maxillofac Implants 2000;15:103-110.
18. Hoshaw S, Bunski J, Cochran G. Mechanical overloading of Branemark implants affects interfacial bone modeling and remodeling. Int J Oral Maxillofac Implants 1994;9:345-360.
19. Quirynen M, Naert I, van Steenberghe D. Fixture design and overload influence marginal bone loss and fixture success in the Branemark system. Clin Oral Implants Res 1992;3:104-111.

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